Scientific Sampling Effects:

Electrofishing California's Endangered Fish Populations

By Jennifer L. Nielsen

ABSTRACT

Standard methods used by biologists around the world for sampling fish populations and determining fish and habitat relationships primarily involve electrofishing. With the recent listings of coastal salmon and steelhead as threatened or endangered, one must ask how electrofishing-induced injury to fish in rare populations relates to "take" under the U.S. Endangered Species Act. Issues related to electrofishing are under discussion in California as federal and state agencies determine how to approach permitting for monitoring and research activities in rivers containing protected fish populations. Many problems have been discussed in the literature based on short- and long-term injury to individual fish from different forms of electrofishing. To date no standard approach for this technology exists that will allow effective surveys without probable injury to some portion of the fish population. How electrofishing injuries made at the individual fish level translate into population effects has not been adequately studied. In many areas of central and southern California, however, where the numbers of salmon and trout can be very small, and effective population size is frequently less than 25 breeding pairs, accumulated effects due to electrofishing may be significant. This paper reviews the electrofishing literature published during the last nine years. Based on this review and personal experience, I believe fisheries biologists frequently electrofish without considering potential harm or alternative methods. Therefore, I suggest the American Fisheries Society (AFS) develop a set of guidelines for least-invasive sampling methodologies, and adopt a policy on the ethical use of electrofishing for use by federal or state agencies to regulate all electrofishing activities in habitats containing wild fish. I believe other noninvasive study methods should be required in areas where it can be shown that electrofishing may significantly reduce a population's ability to persist.

Recent listings of coho (*Oncorhynchus kisutch*) and steelhead (*O. mykiss*) populations throughout California as threatened or endangered Evolutionarily Significant Units (ESUs) under the U.S. Endangered Species Act [steelhead: *Federal Register* Vol. 61(155), 9 August 1996; coho: *Federal Register* Vol. 61(225), 11 November 1996] have led to controversy and confusion about the use of electrofishing as a fisheries management tool for population surveys and scientific studies. At the southern extent of their natural range in California, many populations of anadromous salmonids are either extirpated or have declined to less than 10% of their recorded historic abundance (Weitkamp et al. 1995; Busby et al. 1996). Effective population size (i.e., the number of fish successfully contributing to the next generation) is less than 25 breeding pairs in many California salmonid populations (Brown et al. 1994; McEwan and Jackson 1996). Little is known about recruitment patterns or minimum viable population size for the remaining stocks. Scarcity of wild salmonids in many California riverine systems and numerous publications on injury, short-term mortality, and growth effects caused by electrofishing have brought into question the use of this technology when scientists study threatened or endangered groups of fishes.

Fisheries professionals have used electricity in freshwater habitats to capture fish, legally and otherwise, since the 1930s, when automobile batteries and electric generators were used as fishing techniques. Compared with the earlier alternatives of dynamite and poison used to capture fish, the introduction of electrofishing appeared a humane, effective technical improvement that was adopted and further developed by the scientific fisheries community. However, a dialogue on potential harm to the aquatic community due to electrofishing started early in the development of this technology. As early as 1949, Hauck recorded harmful effects of alternating-current (AC) electrofishing in large rainbow trout (*Oncorhynchus*

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mykiss). However, Pratt (1955) reported negligible immediate and delayed mortality in brown trout (*Salmo trutta*), brook trout (*Salvelinus fontinalis*), and rainbow trout subjected to alternating and direct (DC) electrical fields in streams with specific physicochemical characteristics. He argued that in such areas electrofishing would "prove valuable in estimating stream-fish populations" (Pratt 1955:96).

Spencer (1967) questioned stress and injuries sustained by fish when they were subjected to electrical shock, while Horak and Klein (1967) examined stamina and mortality in fish subjected to intense electrical current. Vertebral injury and other physiological responses to electric current in rainbow trout were explored by Schreck et al. 1976 (and literature therein). Whaley et al. (1978) reported lethality of electroshock in two freshwater species. That paper examined the mortality of fantail darters (*Etheostoma flabellare*) exposed to different pulse frequencies for various durations of exposure and provided guidance for minimizing injury during electrofishing. Mesa and Schreck (1989) were the first to describe changes in fish behavior due to electrofishing. McCrimmon and Bidgood (1965) found no evidence of direct harm to the vertebral columns of rainbow trout in relation to electrofishing.

Because of my involvement as a geneticist in the California salmonid listings and recovery programs, and the fact that up until 1989 I spent considerable time using an electrofisher to study Pacific salmonids throughout the Pacific Northwest, I recently did a *BIOSIS* survey of the subject (electrofishing) to gain a fresh perspective on electrofishing research and applications. This survey resulted in a list of 295 peer-reviewed publications (1989–1997) from 83 international scientific books, bulletins, or journals published in 8 languages. The American Fisheries Society's *North American Journal of Fisheries Management* outpaced all the rest of the journals with 82 published articles (28% of the total survey). These papers covered issues related to 64 fish species, eels, and lampreys; reviews of electrofishing effects on aquatic invertebrates and macroinvertebrates; and several articles on electrofishing freshwater shrimp. My survey showed how pervasive the use of electrofishing has become among fisheries professionals throughout the world.

I divided the *BIOSIS* list of electrofishing papers into three categories: methods, effects, and general surveys. Methods papers dealt with the efficient and effective use of electrofishing, different technical and sampling approaches, and comparisons of electrofishing with other sampling protocols (hook-and-line or snorkeling). Effects papers dealt with the general effects of electrofishing on fish and invertebrates. I grouped the effects papers into two subcategories: positive (no observed or recorded negative effects = 20%) and negative (reported injury and/or mortality = 80%). General surveys were reports of fish abundance, assemblage, behavior, and distributions from studies where electrofishing was reported as the primary sampling method. The 295 papers broke down by category as follows: 68% general survey, 25% methods, and 7% effects. In other words, during the last nine years most reports involved general surveys in which electrofishing was used to collect data but did not discuss direct impacts of electrofishing on the aquatic community.

Where electrofishing injury and/or mortality rates were discussed in the literature, I found many different reported causal mechanisms and types of analysis (see review in Hollender and Carline 1994). In addition to mortality, reports in the literature of injuries to fish due to electrofishing describe spinal hemorrhages, fractured vertebra, spinal misalignment, and separated spinal columns (Dalbey et al. 1996; Thompson et al. 1997a; Kocovsky et al. 1997). Differences in injury and mortality rates were reportedly due to size and/or age of the fish (Habera et al. 1996; Thompson et al. 1997a). Most studies in my survey looked at injury due to electrofishing in adult fish, not juveniles for which stress, not injury, can be the main problem when electrofishing (P. Bisson, U.S. Forest Service; S. Parmenter, California Department of Fish and Game, pers. comm.). Comparisons of injury due to handling methods during and after shocking were discussed by Mitton and McDonald (1994a, b). Muth and Ruppert (1997) examined growth and survival of razorback sucker (*Xyrauchen texanus*) eggs and larvae subjected to electrofishing.

Indirect factors were often considered in relationship to direct


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In the Pacific Northwest electrofishing is thought to harm only a fraction of the total fish that are actually captured during a study.

electrofishing effects. Differing rates of accumulated injuries due to electrofishing were reported with changes in the duration of capture sequence; i.e., the amount of time taken to complete electrofishing within a sample area (McMichael 1993)], and the frequency of sampling through time (years) (Kocovsky et al. 1997). Crew efficiency (Hardin and Conner 1992) and operator skill (Thompson et al. 1997b) also were mentioned as factors contributing to the scale of electrofishing effects on fish. Fish injury rates varied due to voltage level (Hudy 1985; Dwyer and Erdahl 1995), pulse frequency (Reynolds and Kolz 1995; Sharber et al. 1995), and other technical variations in electrical settings such as band width and pulse rate (Sharber and Carothers 1988; Fredenberg 1992; Snyder 1992; Sharber et al. 1994; Dalbey et al. 1996). Changes in injury rate due to the use of different forms of alternating and/or direct current also were found in this literature (Hollender and Carline 1994; Dalbey et al. 1996).

Many concerned biologists believe they have learned to use electrofishing techniques for efficient sampling with good recovery and negligible injury or mortality. However, sublethal effects are not always externally evident in electrofished populations, and biologists appear to greatly underestimate spinal injuries from external examinations alone. Dalbey et al. (1996) indicated that only 2% of the captive wild rainbow trout they surveyed had externally visible deformities, but X-ray analysis used to quantify sublethal injuries after nearly one year in captivity indicated 37% of the population had actually been injured. Hollender and Carline (1994) surveyed the published literature and their own data for a wide range of electrofishing variables (current, voltage, frequency) and stream conductivity in relationship to injury in brown, rainbow, and brook trout (*Salvelinus fontinalis*). They reported that on average 24% of trout sampled in their natural environment suffered spinal injuries, hemorrage, or both during AC and pulsed-DC backpack electrofishing.

The literature does contain discussions of short- and long-term negative sublethal effects of electroshock in fishes. These include differences in growth rate and/or body condition in individual fish during variable periods of time after electrofishing (Gatz et al. 1986; Taube 1992; Dwyer and White 1995; and others). In their study of spinal injuries resulting from electrofishing, Dalbey et al. (1996) indicated that uninjured fish showed significantly better condition after one year than injured fish at even the lowest level of severity of injury. One study showed that sublethal spinal injuries accumulated through time in populations subjected to repeated electrofishing surveys (Kocovsky et al. 1997).

Kocovsky et al. (1997) found no population-level effects based on estimated abundance in salmonids after eight years of electrofishing surveys in three Colorado streams. Despite increased incidence of sublethal spinal injuries through time, salmonid abundance remained stable in the study sites. In this same study the abundance of longnose suckers (*Catostomus catostomus*) did decline, suggesting that continuous electrofishing may have lowered the species' survival. The study suggests that the spatial and temporal population dynamics of all species affected by electrofishing surveys, regardless of the target species, need to be carefully considered when judging the impacts of electrofishing.

Other than Kocovsky et al. (1997), no definitive studies exist on the influence of sublethal injury in fish subjected to multiple electrofishing episodes throughout long periods of time (see Dwyer and White 1997, Thompson et al. 1997b). Most minor or moderately injured fish usually survive and appear to behave normally (Snyder 1995). In their 1995 paper, Schill and Beland expressed concern that although they could find only four studies that examined long-term mortality—all of which demonstrated no significant differences in survival between electrofished and control samples—the thought that electrofishing harms stocks still persists. They called for more studies of the effects of long-term electrofishing injury at the population level.

In the Pacific Northwest, despite recent declines in the overall numbers of wild spawning adults, juvenile salmonids (the subject of most electrofishing populations surveys) remain distributed throughout basin habitats. Under these conditions, electrofishing is thought to harm only a fraction of the total fish captured during a study and an even smaller fraction of the entire stream population contained in the study area. When the total number of fish in a river is considered as a single unit, the influence of electrofished-induced injury in a few habitats becomes nonsignificant when compared to natural mortality (Shill and Beland 1995). One problem with the conceptual model used to support a lack of electrofishing impacts at the population level is that it includes no information on the diversity of scale at which individual fish may represent important subsections of the general population.

Random patterns in the distribution of sample organisms within a stream may not be the case in studies of salmonids in dynamic and arid

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All electrofishing activity should be carefully evaluated for cost, benefits, and drawbacks.

environments of central and southern California, where small, aggregate populations have been documented, and recruitment remains very low for many year classes (Brown et al. 1994; Busby et al. 1996). Population sampling effects may not be limited to small, rare groups of fish. Effective population size may be very different in stocks with overlapping life-histories such as summer- and winter-run steelhead in the Middle Fork Eel River (Nielsen 1996) or winter- and spring-run chinook in California's Central Valley (Nielsen et al. 1994b). Variation in life-history patterns within a species in any basin can create a mosaic or patchwork of unique population substructure among basin habitats, and potential electrofishing impacts will vary with the relationship between the population's and sample's genetic structure or evolutionary history.

Equally important to the current discussion is that rare California salmonid populations contain unprecedented genetic diversity for their species and this unique genetic diversity may not be randomly distributed throughout their Evolutionarily Significant Unit (ESU) or even within any one basin (Nielsen et al. 1994a; Nielsen et al. 1997, 1998). At the southern geographic edge of the range for salmonids, it is difficult to ignore negative effects on growth or survival resulting from sampling wild populations that could have significant consequences at the population level through time.

Given the potential diversity of scale in genetic and/or phenotypic substructure in the distribution of a species within a stream or basin, it would be useful to know how small a population has to be before it might suffer long-term damage from electrofishing. At what point does the argument break down that eliminating electrofishing to protect stocks is biologically unfounded and unnecessary because population level effects are highly unlikely?

Any extensive literature review will reveal that electrofishing has served many positive purposes in the fisheries community during the last 60 years. Clearly, fish biologists who deal with listed populations run into a problem with this technique when sublethal injury leading to a decline in condition and fitness could be legally construed as a "take" under the Endangered Species Act (ESA). Under a strict interpretation of the ESA, electrofishing may represent a "take" as an action that has the potential to harm listed fish. Under Section 7 requirements, federal and state agencies as well as private organizations or individuals may be considered legally culpable for electrofishing in areas where a listed fish population is found.

This presents the research and conservation communities with a difficult dilemma. Some qualitatively accurate and consistent measure of population abundance is needed to address conservation issues and recovery in rare or endangered populations, but the most effective tool in common use on fishes could push rare populations closer to extinction by reducing the fitness and potential reproductive success of a small number of individuals. Researchers may be fooling themselves into thinking quantitative excellence is only available through electrofishing because they are used to the methodology, and under many conditions it appears to work better than any other tool currently available. This level of confidence, however, is frequently not supported by hard reality. Many studies have shown that electrofishing provides a relatively accurate estimate of abundance under the best conditions, but estimates of abundance can vary significantly under different environmental and technical constraints. The accuracy of these estimates is a question of relevant scales set by individual biologists, not necessarily a rigorous or consistent application of technique. Statistically valid estimates of abundance (i.e., removal or capture-recapture models) are only as good as the raw data that go into the model.

Despite published studies on the possible harm of electrofishing, no consensus has been reached within the scientific community on a methodology that will provide operational efficiency and precision with negligible injury. During a 10 February 1998 electrofishing workshop in Ukiah, California, recommendations for electrofishing guidelines and protocols were discussed by 48 participants from the National Marine Fisheries Service, California Department of Fish and Game, other federal and state fish and forestry agencies, academics, tribal representatives, representatives from the timber industry, and fisheries consultants. Draft recommendations from this meeting are in review and have not been officially adopted by any of the participating agencies or individuals. The draft document included general recommendations such as using an "electrofishing decision tree...to help find the appropriate electrofisher settings for specific watersheds." Sampling should begin by using direct current (DC), and in cases with unsuccessful captures using DC, "lower voltages with pulsed direct current" should be used for fish collection, the document states. The draft goes on to suggest that "if fish capture is unsuccessful with low voltages, increased voltage and pulse frequency" should be used.

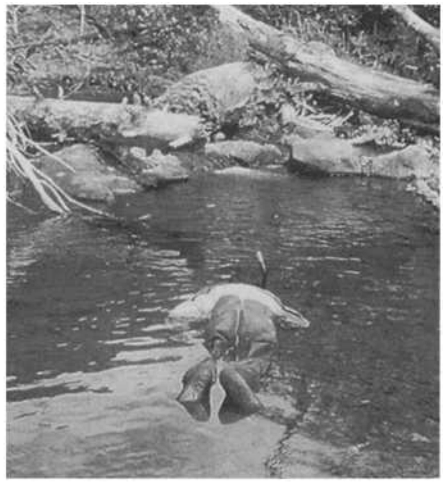
Other recommendations made as a result of this workshop considered operator experience and crew training ("must be led by experienced crew leader"), conductivity measurements ("should be made to evaluate electrofishing settings"), duration ("do not electrofish in one location for an extended period"), anesthetics (use carbon dioxide, clove oil, or no anesthetic at all), sample work up, data management, and monitoring fish condition after capture. While this represents a commendable first approach to reach a broad consensus on electrofishing protocols, the document's lack of specific criteria for movement along the "electrofishing decision tree" leaves a lot to be desired. Despite the fact that far more specific guidelines are available from the technical literature, the document gives no directions on limits or restrictions to any electrofishing techniques under any set of circumstances.

In sensitive areas with few fish left, I believe that statistically relevant data should be gathered by least-invasive means such as snorkel surveys.

Recently many researchers have suggested snorkel surveys as an alternative to electrofishing, and have compared results and limitations for the two methods (Griffith 1981; Hankin and Reeves 1988; Hayes and Baird 1994). This literature discussed many potential problems with snorkel surveys when compared with electrofishing: limitations due to time, fish size bias, a lack of trained and skilled labor, difficult climactic and seasonal conditions, no universal methodology, and no correlation with historical data. Many of these same arguments could have been applied to electrofishing more than 20 years ago and still hold true today.

In their comparison of estimated abundance based on electrofishing (using mark-recapture and removal estimates) and snorkel surveys, Rodgers et al. (1992) concluded that data collected from backpack electrofishing under the mark-recapture model were significantly more accurate than snorkel counts. Techniques for the application of snorkel surveys in estimating fish abundance have evolved significantly since the Rodgers et al. study. Comparisons drawn among sampling methods used to inventory bull trout in Idaho indicated that day snorkeling counts yielded on average 75% of the abundance estimated by electrofishing regardless of habitat type (Thurow and Schill 1996). This same study indicated increased efficiency in estimating abundance of large fish most prone to electrofishing injury using snorkel techniques.

A master's of science thesis in process at Humboldt State University is examining the statistical validity of population estimates made using snorkel counts. This study presents criteria under which snorkel surveys using the method of "bounded counts" may be used to reduce reliance on electrofishing for abundance estimates (Dave Hankin, Humboldt State University, pers. comm.). This method appears to hold substantial promise under certain conditions: (1) when the number of fish within the habitat unit is small (<20 fish per species), (2) when it is theoretically possible that a diver could count all fish present, and (3)



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Many researchers have suggested snorkel surveys as an alternative to electrofishing.

when it can be assumed that a diver will not count individual fish more than once. These conditions are limited, but they reflect exactly the conditions of low abundance that might be expected for endangered species of fish.

It is important, however, to recognize situations when electrofishing is the only effective tool available to the fisheries biologist. Snorkeling probably cannot replace electrofishing when working in very cold water (Rodgers et al. 1992; Hillman et al. 1992), in habitats with extremely shallow stream depths, or in large or turbid rivers. Collecting fish for telemetry or tagging studies, collecting broodstock for recovery programs, and removing exotic species frequently require electrofishing techniques for successful results. Even under these circumstances I would recommend some form of decision-making process to ensure proper use of appropriate equipment and verification of well-trained, experienced personnel. Electrofishing activity should be undertaken only after a carefully evaluation of all benefits against potential risks (Kocovsky et al. 1997; Muth and Ruppert 1997). When working with threatened and endangered fish populations, I recommend state and federal agencies implement some form of permitting system to regulate and monitor all electrofishing activities in areas where listed fish may be found.

The symposium, Human Interactions with Aquatic Organisms: Philosophy, Values, and Social Change, held at the 1997 AFS Annual Meeting in Monterey, California, highlighted many of the conflicts and issues professional fisheries scientists must address in the next century as human values placed on aquatic resources change. The listing of salmonids at the southern extent of their range in areas around Los Angeles and Monterey Bay as Evolutionarily Significant Units of the genus *Oncorhynchus* represents a dramatic change in public opinion concerning these fish populations. For the last 100 years Californians, perhaps more than anyone else, have dammed their rivers and destroyed aquatic habitat in the name of development and progress. Clearly, the tide is changing in many communities where healthy aquatic ecosystems are considered worth the price of dam demolition and river reconstruction.

In an effort to improve fish passage and habitat for rare or endangered species, the U.S. Congress has been petitioned by many nongovernment agencies to include provisions for funding removal of numerous old, ineffective dams (Reisner 1998). One of these dams, the Rindge Dam on Malibu Creek, lies just north of the dense urban center of Los Angeles. Its removal would open 14 km of freshwater habitat for the southern-most population of anadromous steelhead at a cost of several million dollars. If part of society is committed to protecting and restoring these unique groups of fish, biologists dealing with their conservation and recovery have a legal and moral obligation to avoid contributing in any way to their further decline.

In my *BIOSIS* survey only one article from Germany directly discussed animal protection during electrofishing (Schultz 1995). Changing social values based on concepts of ecology and ecosystem management will alter how scientists and society interact with nature. Electrofishing as currently practiced by fish biologists may pose significant potential risks to wild fish populations, including some not currently listed as threatened or endangered under federal or state laws. All electrofishing activity should be carefully evaluated for cost and benefits that result from its use.

Through its leadership role in science-based information dedicated to fisheries management and policy, the AFS should develop a set of guidelines for least-invasive sampling methodologies and adopt a policy on the ethical use of electrofishing by federal or state agencies to control and monitor electrofishing activities under their jurisdiction. I believe that other non-invasive study methods should be required in areas where it can be shown that electrofishing may significantly reduce a population's ability to persist. At the very least, the activity of electrofishing by any individual, organization, or corporation should be strictly regulated by the agencies overseeing recovery of listed fish species with reference to guidelines and criteria established by the Society.

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